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Research Article

Comparative Analysis of HIRARC and HIRADC Methods in Occupational Safety Risk Management for Girder Erection Projects

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Abstract

This research investigates the integration of Occupational Health and Safety Management Systems (OHSMS) into girder erection activities within a major infrastructure development, emphasizing a comparison between two risk assessment approaches: HIRARC (Hazard Identification, Risk Assessment, and Risk Control) and HIRADC (Hazard Identification, Risk Assessment, and Determining Control). The objective is to assess which method offers more precise and actionable guidance for hazard mitigation in the context of heavy structural lifting. A qualitative case study was conducted at the Kayu Agung–Palembang–Betung toll road project in Indonesia. Field-based data collection included direct observations, documentation review, and stakeholder interviews. Each method was applied to systematically identify occupational hazards, evaluate their potential impacts, and formulate appropriate control strategies. Further analysis was performed to determine the safety factor of 180-ton and 250-ton cranes involved in the girder installation. A projected cost for OHSMS implementation was also calculated. The study reveals that HIRADC delivers clearer control recommendations and more targeted risk prioritization compared to HIRARC, making it better suited for high-risk construction scenarios. The larger crane, with a safety factor of 1.89, proved more reliable than the 180-ton model (1.65). The total cost required to implement comprehensive safety procedures was estimated at IDR 159,435,000. Critical risks identified include girder drops, worker falls from height, and contact with moving equipment. The insights gained from this study can enhance occupational safety planning and serve as a reference for similar engineering projects in emerging economies.

Keywords: *HIRARC, Girder, Erection, Safety, Occupational*

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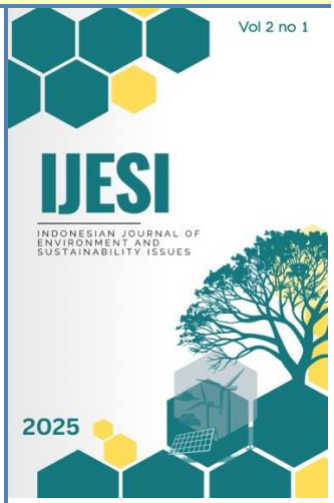

INTRODUCTION

The development of infrastructure serves as a foundation for national progress, especially in emerging economies such as Indonesia, where improved connectivity supports economic integration and regional mobility. Among various infrastructure components, road and bridge networks are key to supporting logistics and transportation systems. As the Indonesian government continues to advance large-scale national strategic infrastructure projects, the importance of implementing construction methods that are not only efficient but also safe has become increasingly apparent [1]. The process of girder erection represents one of the most technically demanding phases in bridge construction, as it involves lifting heavy prefabricated components into position using cranes and other large-scale equipment. These tasks expose workers to significant hazards, especially when carried out at heights or in the presence of moving mechanical systems [2], [3], [4]. Therefore, thorough planning and implementation of lifting strategies are essential to reduce structural failure and safety incidents [5], [6]. Failures in this stage can lead to serious consequences including workplace injuries, delays in project completion, and damage to structural components [7], [8]. For this reason, the application of a well-structured occupational health and safety system is critical in such high-risk environments. In high-risk construction environments, occupational hazards stem not only from equipment-related incidents but also from environmental exposures such as noise, heat, and poor visibility. Emphasized how noise generated by vehicle traffic can significantly impact worker safety and performance, highlighting the need for integrated safety assessments that address both physical and environmental risks [9]. Therefore, the application of a well-structured occupational health and safety system is critical in such high-risk environments.

To address these safety challenges, the construction sector increasingly relies on Occpational Health and Safety Management Systems (OHSMS), which provide guidelines for hazard identification, risk analysis, and the implementation of preventive measures. Among the widely applied tools in this system is the HIRARC method (Hazard Identification, Risk Assessment, and Risk Control), which has been adopted in a variety of sectors due to its adaptability and clarity [10]. HIRARC enables systematic identification of hazards and encourages proactive control strategies to reduce workplace risks before incidents occur. However, the unique complexity of girder erection—where workers, equipment, and structures interact—demands more detailed guidance in selecting control actions. As a response, HIRADC (Hazard Identification, Risk Assessment, and Determining Control) was introduced to refine the control selection process through more structured evaluations. While both methods share a common foundation in risk management, HIRADC emphasizes more specific decision-making processes, especially relevant in hazardous operations such as heavy lifting. Despite its potential, the practical use and comparison of HIRADC in construction safety planning remain limited.

Bridge erection projects in toll road development require safety assessments that align not only with procedural risks but also with engineering considerations such as equipment load capacity. Activities such as lifting girders require integration of technical calculations—like crane safety factor assessments—into the safety planning process [11], [12], [13]. These considerations are often overlooked in risk analysis studies, despite their impact on lifting stability and worker safety. Additionally, most studies on risk assessment tools fail to include the financial aspect of implementing OHSMS, such as budgeting for safety equipment and procedures. **[S]** Incorporating both safety and cost aspects into the decision-making framework is essential for realistic planning

and resource allocation [14]. Without this integration, critical hazards might be underestimated or improperly mitigated. Although girder erection is inherently high-risk, few empirical studies have examined the comparative effectiveness of HIRARC and HIRADC while also addressing crane safety and implementation costs [15]. Thus, a study that combines methodological evaluation with technical and financial analysis is necessary to support safer construction practices in large-scale projects.

Previous investigations have explored the application of HIRARC in various industrial and construction contexts, including in energy facilities [16], [17], tower crane operations [18], loading ramps [19], manufacturing processes [20], and infrastructure such as international airports [21]. Other researchers have developed hazard documentation using HIRARC in glass production [22], assessed industrial accident risk [23], and applied the method in general construction [24] and asphalt concrete industries (Nur et al., 2023). Despite their broad scope, these studies generally rely solely on HIRARC and do not compare its performance to HIRADC. Moreover, none of the studies incorporate crane safety factor analysis or cost projections related to safety program implementation—factors that are crucial in bridge construction projects involving girder erection. Therefore, there is a significant research gap involving both comparative methodological assessment and integration of technical and financial dimensions, which this study aims to address through an applied case study approach.

This study aims to evaluate and compare the effectiveness of HIRARC and HIRADC methods in identifying and managing occupational risks during girder erection work. In addition, it assesses the crane safety factor and estimates the budget required for implementing a comprehensive OHSMS plan. Through this approach, the research intends to provide a more integrated and applicable safety planning framework for high-risk construction projects.

METHODS

Research Design

This research was conducted using a case study approach, focusing on girder erection activities within the Kayu Agung–Palembang–Betung toll road construction project in South Sumatra, Indonesia. The study is designed to compare two occupational risk assessment frameworks—HIRARC (Hazard Identification, Risk Assessment, and Risk Control) and HIRADC (Hazard Identification, Risk Assessment, and Determining Control)—by applying both to the same work context. This comparative framework was chosen to maintain consistent environmental and operational variables while highlighting the practical differences between the two methodologies. A combination of qualitative and quantitative techniques was used to enrich the analysis, including on-site observation, stakeholder interviews, technical documentation review, crane safety factor calculations, and estimation of implementation costs related to the Occupational Health and Safety Management System (OHSMS). The integration of technical and contextual data allowed for a comprehensive evaluation of each method's effectiveness in real construction conditions.

Instrument

To gather relevant data, this research employed several instruments adapted to both qualitative and quantitative needs. Observation checklists were used to record real-time site conditions and compliance with standard safety procedures. Risk assessment was carried out using structured forms based on HIRARC and HIRADC guidelines, enabling side-by-side comparison of identified

hazards and recommended control measures. Interview guides were developed to elicit targeted information from participants based on their job functions and expertise. Additionally, project-related documents—such as crane manuals, lifting plans, and job safety analysis sheets—were examined to extract technical data. Engineering calculation templates were used to compute the safety factors (SF) for the cranes used (180-ton and 250-ton), while a cost planning sheet was designed to estimate expenditures required for full-scale implementation of SMK3 (OHSMS). All instruments aligned with international safety standards (e.g., ISO 45001, OSHA) and Indonesian regulatory frameworks to ensure validity and applicability in both academic and practical settings.

Data Analysis

The analysis process combined qualitative thematic analysis with quantitative engineering evaluation. The data from both HIRARC and HIRADC assessments were compared in terms of the number and severity of hazards identified, clarity of control strategies, and level of preventive detail. Safety factor values for both cranes were calculated based on lifting physics and assessed against standard thresholds for safe operation. Additionally, cost estimation data were summarized using descriptive statistics to provide insight into the financial feasibility of implementing comprehensive safety measures. Finally, a comparison matrix was constructed to visualize and evaluate the methodological differences between HIRARC and HIRADC in practical application, particularly concerning effectiveness, specificity, and integration with technical and financial planning in girder erection.

RESULT AND DISCUSSIONS

Risk Assessment Comparison: HIRARC vs. HIRADC

When both HIRARC and HIRADC were applied to the same work activity—erection of girders—they produced comparable hazard categories, including the risk of material falling, falls from elevation, and injury due to proximity to heavy equipment. However, differences emerged in how each method categorized risks and prescribed controls. HIRARC grouped control measures under general types such as “engineering” or “administrative” without specific action steps, while HIRADC provided clearer, task-specific guidance. For example, while HIRARC recommended “engineering control” to prevent girder falls, HIRADC suggested a more precise response involving detailed lifting inspections and redundant support mechanisms. This distinction highlights HIRADC’s advantage in high-risk environments where procedural detail is critical. The results of this comparison are summarized in Table 1.

Table 1. Comparison of Risk Identification and Control Recommendations (HIRARC vs HIRADC)

Hazard Description	Risk Source	HIRARC Control Recommendation	HIRADC Control Recomemendation
Girder falling	Crane malfunction	Engineering control	Detailed lifting inspection & secondary support system
Worker falls from height	Inadequate PPE/fall arrest	Use of PPE	Full body harness + double lanyard &

			structured training program
Equipment related injury	Proximity to heavy equipment	Administrative control	Visual warning zones, spotter system and restricted access protocols

Crane Safety Factor Results

The lifting operation employed two cranes of different capacities—180-ton and 250-ton models. Safety factor (SF) analysis was conducted based on the rated capacity of each crane and the actual load imposed during girder erection. The 180-ton crane yielded an SF of 1.65, while the 250-ton crane achieved a value of 1.89. Both results fall within permissible safety thresholds, though the 250-ton crane offered a larger safety margin, which makes it more reliable under demanding field conditions. These findings support the importance of integrating technical calculations into safety planning. Details are shown in Table 2.

Table 2. Crane Safety factor Calculation

Crane Type	Rated Capacity (tons)	Load Applied (tons)	Calculated SF	Interpretation
180-ton crane	180	109.09	1.65	Acceptable but lower safety margin
250-ton crane	250	132.28	1.89	Higher reliability for lifting

Budget Estimate for SMK3 Implementation

The cost of implementing a full-scale occupational safety management plan during girder erection was calculated by identifying individual components such as personal protective equipment, fall arrest systems, safety briefings, and emergency response tools. Based on actual project records and market pricing, the total budget was estimated at IDR 159,435,000. Notably, the HIRADC-based planning approach led to more itemized budgeting because of its more specific control recommendations. The breakdown of these costs is shown in Table 3.

Table 3. Estimated SMK3 Implementation Costs

Item Description	Quantity	Unit Price (IDR)	Total (IDR)
PPE sets (helmets, vests)	50	300,000	15,000,000
Fall protection gear	20	1,200,000	24,000,000
Safety signage and banners	30	150,000	4,500,000
Safety briefing sessions	10	1,000,000	10,000,000
Emergency response kits	10	2,000,000	20,000,000

Professional safety staff	Lump sum	-	85,935,000
Total			159,435,000

This financial data reinforces the necessity of incorporating cost considerations into the risk management process, ensuring that safety planning is both effective and realistically implementable.

The comparative analysis between HIRARC and HIRADC conducted in this study illustrates a critical difference in the level of clarity, specificity, and applicability of each method. While both frameworks are designed to identify, assess, and manage workplace hazards, HIRADC demonstrated a higher level of operational precision when applied to the high-risk activity of girder erection. This finding is in line with Masykur (2022), who emphasized that HIRADC encourages more detailed hazard breakdowns and role-based risk allocation, especially in structural lifting contexts . The structured nature of HIRADC allows for more actionable planning, as reflected in its recommendation of specific engineering measures like redundant lifting inspections and backup support systems. In contrast, HIRARC grouped similar risks into broad categories with general control suggestions, making it more suitable for baseline risk assessments but insufficient for technically complex projects. Ibrahim (2023) further reinforced this by demonstrating that HIRADC implementation leads to improved internal audit outcomes and compliance with OHSAS 18001. In this study, the detailed differentiation between similar hazards—such as falling materials due to crane failure and worker falls due to poor PPE—illustrates the superiority of HIRADC in prescribing tailored interventions. Therefore, the selection of assessment methodology has direct implications on the depth and effectiveness of safety control planning, particularly in infrastructure development environments with critical lifting operations.

In addition to methodological clarity, this study also incorporates a quantitative analysis of crane safety factors, offering an engineering-based lens to validate lifting strategy reliability. The analysis revealed that the 250-ton crane achieved a safety factor (SF) of 1.89, compared to the 180-ton crane's SF of 1.65. Although both values are within acceptable thresholds, the higher SF of the 250-ton unit signifies greater resilience against dynamic loads, misalignment, and unpredictable field conditions. These results are supported by the work of Rachman (2020), who found that selecting equipment with higher SF values contributes to a reduction in operational interruptions and material damage incidents during beam erection tasks. Furthermore, Hadi (2021) emphasized the influence of lifting angles, load swing, and weather on SF performance, making pre-lift calculations a vital safety component. The present findings strengthen the argument that safety engineering and procedural risk assessment should be integrated rather than treated as parallel efforts. Using HIRADC in combination with crane safety calculations provides a dual layer of control—proactive through planning and reactive through equipment margin validation. Such integration not only enhances safety outcomes but also improves worker confidence and operational discipline on-site.

Another crucial contribution of this study lies in its financial dimension, particularly in estimating the cost of implementing SMK3 during girder erection activities. The total estimated budget of IDR 159,435,000 includes expenditures for PPE, fall arrest systems, safety briefings, emergency response kits, and professional safety oversight. Unlike many studies that separate safety planning from budgeting, this research embeds cost analysis directly into the risk management framework.

This approach is consistent with the findings of Egar (2017), who reported that aligning budget planning with hazard-specific controls improves procurement efficiency and minimizes safety compliance delays in toll road construction. Notably, the HIRADC method allowed for a more granular and traceable cost breakdown, linking each control recommendation with its associated financial component. This level of integration is critical for large-scale infrastructure projects, which often face scrutiny in cost management and safety auditing. Moreover, the alignment with Permen PUPR No. 5/2014 reinforces the regulatory relevance of this study, as the policy mandates traceable and measurable occupational safety plans for public infrastructure development. Integrating financial planning with hazard management, as demonstrated in this study, not only improves implementation readiness but also supports strategic decision-making at the project management level.

Collectively, the results of this research provide compelling evidence that adopting HIRADC in place of or alongside HIRARC offers substantial advantages in high-risk, technically demanding construction activities. The method's prescriptive nature enhances clarity in safety protocols, while its compatibility with engineering analysis and budget structuring ensures a more holistic approach to occupational risk management. The comparative design of this study, supported by real project data and technical calculations, contributes meaningfully to the existing body of literature on construction safety systems. Findings from similar studies (Putra, 2021; Haryanto, 2022) further suggest that integrated safety planning reduces not only incidents but also administrative burden and insurance liabilities. Nonetheless, this study recognizes that implementation success depends not only on method selection but also on organizational culture, training, and continuous monitoring. Future research should therefore consider longitudinal designs that measure post-implementation outcomes, such as accident reduction rates, cost-efficiency improvements, and worker satisfaction. By advancing a structured and economically responsive approach to construction safety, this study aims to inform policymakers, project managers, and safety engineers seeking evidence-based practices for large-scale infrastructure projects.

Implication

The findings of this study carry several practical, managerial, and academic implications. Practically, project managers and safety officers in high-risk construction environments can adopt the HIRADC method to enhance the specificity of risk controls, thereby improving compliance with national regulations and international standards. From a managerial standpoint, integrating hazard analysis with engineering validation and budget allocation allows for more efficient resource planning and execution, particularly in infrastructure projects where safety costs are often underestimated. At the policy level, this study supports the refinement of national safety guidelines to emphasize method selection and documentation traceability. Theoretically, the study contributes to the literature by demonstrating that hazard assessment methods can and should be aligned with technical and financial decision-making frameworks. These implications underscore the importance of moving beyond procedural safety checklists toward comprehensive, integrated systems that reflect the complexity of modern construction projects.

Limitation and Suggest for Future Research

While this study offers valuable insights into the comparative application of HIRARC and HIRADC methods in girder erection activities, it is not without limitations. The research was conducted within the context of a single toll road construction project, which may limit the generalizability of the findings to other infrastructure types such as high-rise buildings, industrial

facilities, or underground structures. Additionally, the analysis of crane safety factors and cost estimation was based on project-specific conditions, which may differ in other geographic or regulatory contexts. Another limitation lies in the cross-sectional nature of the study; it captures risk assessment and planning processes at a single point in time without measuring actual post-implementation outcomes such as reduction in incident rates or improvements in worker behavior. Furthermore, although expert interviews were used, the study did not include quantitative surveys to assess the broader perception of method effectiveness among safety professionals.

To address these limitations, future research should consider adopting a multi-project or multi-site approach to enhance the external validity of the findings. Longitudinal studies are also recommended to evaluate the long-term impact of implementing HIRADC-based safety plans, particularly in terms of accident reduction, cost efficiency, and worker compliance. Comparative studies involving different construction sectors or international settings could offer further insight into the adaptability of these methods across regulatory and cultural boundaries. In addition, integrating digital safety tools—such as BIM-based risk visualization or mobile safety reporting platforms—with HIRADC assessments may open new avenues for enhancing real-time hazard management in dynamic construction environments.

CONCLUSION

This study concludes that the HIRADC method provides a more structured, specific, and practically applicable framework for managing occupational risks in high-risk construction activities such as girder erection, when compared to the conventional HIRARC method. While both approaches effectively identify major hazards, HIRADC distinguishes itself by offering more detailed control recommendations and facilitating stronger alignment with engineering calculations and budgeting strategies. The inclusion of crane safety factor analysis further validates the technical soundness of lifting operations, demonstrating that engineering parameters can and should complement procedural risk assessments. Additionally, the integration of cost estimation into the Occupational Health and Safety Management System (SMK3) planning process highlights the operational advantage of HIRADC in mapping risk controls to real-world budget considerations. These findings have practical implications for project managers, safety officers, and policymakers who seek to improve safety performance in infrastructure development projects. By adopting HIRADC in conjunction with technical validation and financial planning, construction teams can achieve a more holistic, compliant, and efficient approach to safety management. The study also contributes theoretically by illustrating the need for integrated risk assessment models that extend beyond checklist-based compliance into strategic, data-informed planning. Future research is encouraged to expand this model across different construction sectors and evaluate its long-term effectiveness through post-implementation outcome tracking.

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AUTHORS CONTIBUTIONS

All authors contributed significantly to the development of this research. Edo Dinata was responsible for conceptualizing the study, designing the methodology, and leading the data collection and analysis. Krisna Septian Pramayogi contributed to the engineering calculations, particularly in the safety factor assessment of crane operations, and assisted in interpreting technical findings. Aniessa Rinny Ananning focused on literature review, comparative risk assessment (HIRARC vs HIRADC), and drafting the discussion section. Resti Agustina managed project coordination, cost estimation analysis, and performed critical revisions of the manuscript. All authors

CONFLICT OF INTEREST

The authors declare no conflict of interest. This research, including the selection of the research project, study design, data collection, analysis, interpretation, manuscript writing, and decision to publish, was conducted independently and without any external influence or funding sponsor involvement.

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